Studies of Mine Burial in Coastal Environments

Harindra J.S. Fernando, P.I.
Sergey I. Voropayev, Co-P.I.
Don L. Boyer, Co-P.I.
Andjelka N. Srdic, Co-P.I.
Arizona State University
Department of Mechanical and Aerospace Engineering
Tempe, AZ 85287-6106
phone: (480) 965-2807, fax: (480) 965-8746, e-mail: j.fernando@asu.edu

Stephan T. Grilli
University of Rhode Island
Department of Ocean Engineering
Narragansett, RI 02882
phone: (401) 874-6636, fax: (401) 874-6837, e-mail: grilli@oce.uri.edu

Grant Number: N00014-01-1-0349
http://www.eas.asu.edu/~pefdhome

LONG-TERM GOALS

The long-term goal of our research program is to improve scientific knowledge relevant to the understanding and modeling of mine burial in coastal environments. Mine burial is determined by a number of physical processes, for example, bedform migration, scour, sedimentation and impact of mines after free fall. These processes, in turn, are determined by a myriad of governing variables describing the characteristics of background flow, physical properties of the sea floor and mines, and modus of mine seeding. The main focus will be non-walking ship mines of cylindrical shape placed in the shoaling zone.

OBJECTIVES

The scientific objectives of our current research are to: (i) study the evolution of an initially flat sandy beach under nonlinear progressive waves; (ii) investigate the long-term evolution of bottom topography in relation to the mine burial scenario, and (iii) document the behavior of model mines in the shoaling zone. Particular attention is given to: (i) the water motion and ensuing scour around dense cylindrical mines placed on a permeable and movable sand bed under periodic nonlinear waves; (ii) morphodynamics of sand beds under water waves; and (iii) periodic or lasting burial of mines.

APPROACH

In the proposed work, ASU researchers combine their expertise in laboratory and theoretical fluid dynamics with the complementary expertise of the University of Rhode Island (URI) on numerical simulation of wave dynamics to better understand and predict mine scour and burial processes. In particular, detailed flow fields surrounding the mine, coupled mine-sediment dynamics, bedform evolution, scour and mine burial are studied. Detailed laboratory observations and measurements are made during all phases of flow and bedform evolution and their impact on the movement and burial of mines. Physical insights gained and parameterizations developed are being used to improve existing models or develop new models on mine dynamics in the coastal zone.

WORK COMPLETED

Our previous laboratory studies (Lucccio et al., 1998: Voropayev et al., 1998, 1999) were concentrated on the behavior of model mines on horizontal beaches in relatively small wave tanks. Both solid impermeable beaches with artificial roughness or movable sandy beds were considered. In the present work, the above research was extended to achieve the scientific goals noted before. Two sets of experiments were conducted in a large wave tank at located at ASU (Fig. 1).

Figure. 1. A side view photograph showing various features of the experimental wave tank (32 x 0.9 x 1.8 m). The distance between vertical bars is 61 cm.

In the first series of experiments, a sandy sloping bottom was used in the wave tank. First, waves of prescribed characteristics were generated and the bottom topography was allowed to achieve a quasi-steady state. The spatial evolution of wave characteristics was then measured using wave gauges and particle imaging velocimetry, with the aim of (i) calibrating the numerical wave model of Grilli et al. (1999, 2000) and (ii) obtaining input data for numerical simulations of flow around solid objects (mines) placed at the bottom. In the second series of experiments, model cylindrical mines of different sizes and densities were placed along the slope of an initially planar sandy bottom, and their long time evolution was studied. Quantitative data on the background flow characteristics, the behavior of mines and the changes of bottom topography were obtained using high-resolution video cameras and a three-component acoustic Doppler velocimeter (ADV). Physical interpretations were advanced in relation to observations and measurements.

RESULTS

Our research during FY 01 was mainly focussed on the background flow field under nonlinear waves propagating along a sandy slope, water motion and scour around cylindrical mines placed along the slope and the evolution of bottom topography. Using ADV probe and wave gauges, wave heights and velocities were measured at different locations along the slope; see Figure 2 for typical results. Note the enhancement of the wave steepness and the asymmetry of the velocity profiles as waves propagate along the slope. Such strongly nonlinear large amplitude waves are typical of shoaling zones in coastal oceans, and laboratory data pertinent to these nonlinear waves are being used for the calibration and validation of numerical models. Some simulations on mine/flow interactions are being conducted by using the commercial software package FLUENT and the results will be compared with detailed ADV and PIV measurements. Attempts to validate existing scour/burial models are also underway.

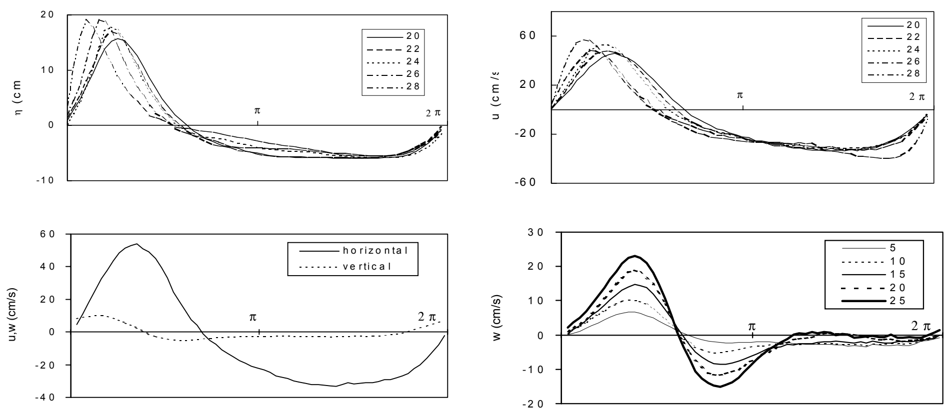

Figure 2. Typical wave elevation (η) and horizontal (u) and vertical (w) velocities for different sections (20-28) and depths (5-25 cm) averaged over 40 periods. The wave frequency was ω = 0.4 Hz and wave height ε_0 = 12.5 cm.

In the experiments conducted to study the scour around mines, circular cylinders of different sizes and densities were used to mimic non-walking ship mines. A range of non-dimensional government parameters, for example, the mobility parameter Ψ, Reynolds Re and Keulegan-Carpenter KC numbers, was employed. Depending on their values, at least two distinct scour patterns were observed (Figs. 3, 5, 6).

Typical observations for moderate values of Ψ and relatively large KC are shown in Fig. 3, where model mines were initially placed on a planar sandy slope perpendicular to waves. Photographs in Fig. 3 show that the bed evolves into a symmetrical (relative to the center of the model mine) scour pattern.

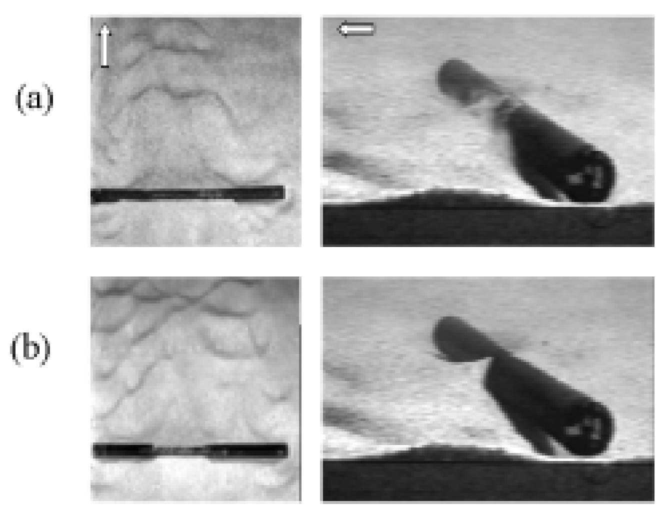

Figure 3. Top (left) and oblique (right) views of scour patterns around a cylinder under periodic waves. Arrows show the onshore direction. D = 3 cm, Ψ = 8, KC = 35, Re = 7500, time t = 65 (a), 230 (b) min after the initiation of wave forcing.

Two dimensional sand waves that are parallel to the mine axis are periodically generated at the onshore side of the mine, and they propagate shoreward due to strong nonlinearity of waves. With time, however, these sand waves become 3D, assuming a horseshoe shape (Fig. 3, top view). A system of primary vortices responsible for these scour patterns is shown schematically in Fig. 4. Energetic tip vortices at the ends of the cylinder play an important role here. At moderate Ψ, the scour process is highly influenced by these tip vortices, which gradually generate scour cavities in the vicinity of mine tips (ends). These scour cavities spread toward the center of the mine, until the mine is merely supported by a small sand mound underneath its central part. Further spreading of scour cavities causes the mine to tip over toward either one side or another. This process recurs, see-sawing the mine periodically and burying it, at least partially.

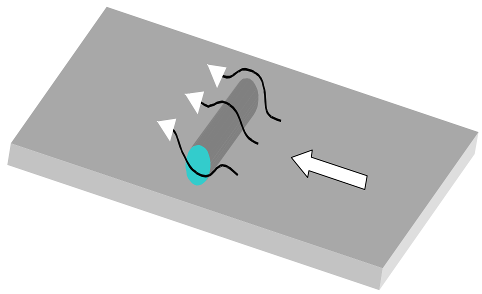

Figure 4. A schematic showing the formation of energetic tip vortices near the ends of a finite-length cylinder during onshore water motion.

At smaller Ψ, the sand wave generation is suppressed because of the presence of a solid body. Tip vortices also become feeble in comparison to the central vortex that is formed, thus suppressing the formation of scour cavities. Sand accumulates along the mine, leading to partial covering of the mine from both of its long sides (Fig. 5).

Figure 5. Sand accumulation along a mine at relatively small values of Ψ (= 4, KC = 20, Re = 6300).

At relatively high Ψ, the changes of bottom topography overshadow the scour. Sand ripples are generated at the bottom and migrate shoreward. When the ripple size is comparable with that of the model mine, the mine is overrun by migrating ripples and is buried and unburied periodically (Fig. 6).

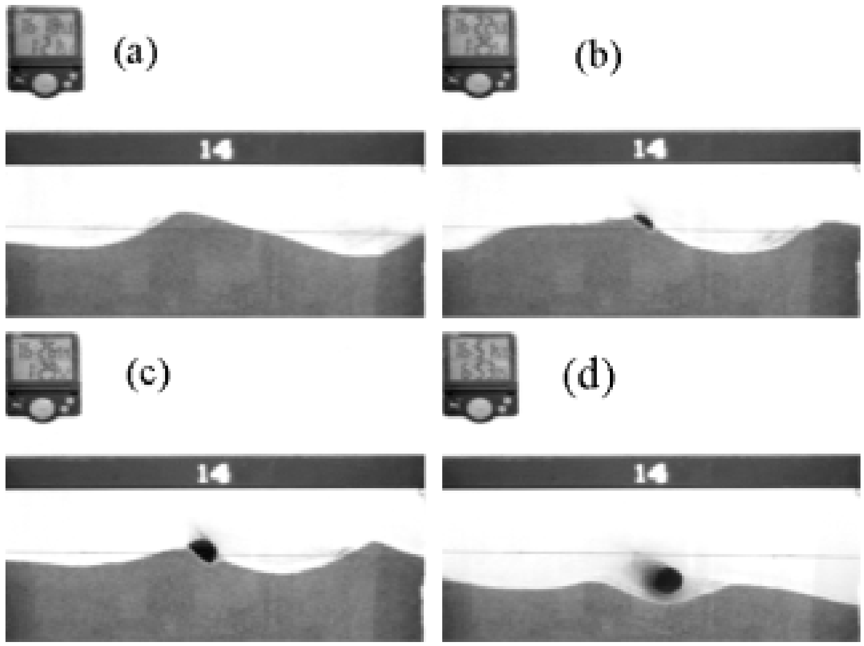

Figure 6. Periodic burial of a model mine under large migrating ripples. D = 4 cm, Ψ = 150, KC = 38, Re = 12000, t = 0 (a), 4 (b), 8 (c) and 320 min (d). Typical period of burial is approximately 22 min and the last frame (d) was taken after 14.5 burial periods.

IMPACT/APPLICATIONS

The scour and burial of large dense cylindrical objects, such as ship mines, on a sandy sloping bottom submerged in the wave boundary layer typical of a coastal zone is not well understood from a fundamental point of view. This project has made fundamental advances in this regard by utilizing integrated laboratory and theoretical/numerical approaches. Field data taken by the Naval Research Laboratory is also being examined to ascertain the efficacy of laboratory studies in predicting mine behavior in oceanic wave boundary layer.

TRANSITIONS

We maintain close contacts with Dr. Todd Holland from the Naval Research Laboratory with regard to studies on mine dynamics in coastal zone. Dr. Zoe Lacroix from Arizona State University is attempting to develop a knowledge-based intelligence system to facilitate effective utilization of our laboratory data and field data available from other sources.

RELATED PROJECTS

This project is linked to another laboratory modeling program that is being funded by the ONR Coastal Sciences Program (PI: Dr. Don Boyer). This latter project also has close ties with NRL personnel at the Stennis Space Center and deals with mine walking in the surf zone, in contrast to non-walking mines in the shoaling zone considered in the project reported herein.

REFERENCES

Luccio, P.A., Voropayev, S.I. Fernando, H.J.S., Boyer, D.L., Houston, W.N. 1998. The motion of cobbles in the swash zone on an impermeable slope. *Coastal Engineering*., **33**, 41-60

Voropayev, S.I., Roney, J., Boyer, D.L., Fernando, H.J.S., Houston, W.N. 1998. The motion of large bottom particles (cobbles) in a wave-induced oscillatory flow. *Coastal Engineering*, **34**, 197-219.

Voropayev, S.I., McEachern, G.B., Boyer, D.L., Fernando, H.J.S. 1999. Dynamics of sand ripples and burial/scouring of cobbles in oscillatory flow. *Applied Ocean Research*, **21**, 249-261.

Grilli, S.T., Horrillo, J. 1999. Shoaling of periodic waves over barred-beaches in a fully nonlinear numerical wave tank. *Intl. J. Offshore and Polar Engng.,* **9**(4), 257-263.

Grilli, S.T., Guyenne, P., Dias, F. 2001. A fully nonlinear model for three-dimensional overturning waves over an arbitrary bottom. *Intl. J. Numer. Methods in Fluids,* **35** (7): 829-867.

PUBLICATIONS

Voropayev, S.I., Cense, A. W., McEachern, G.B., Boyer, D.L. and Fernando, H.J.S. 2001. Dynamics of cobbles in the shoaling region of a surf zone. *Ocean Engineering*, 28(7), 763-788.

Voropayev, S.I., Cremers, M.F.G., Boyer, D.L. and Fernando, H.J.S. 2001. Morphodynamics and burial/scouring of cobbles in the shoaling region of a surf zone. *Journal of Geophysical Research,* under revision.

Voropayev, S.I., Cremers, M.F.G., Boyer, D.L. and Fernando, H.J.S. 2001. Dynamics of the burial of cobbles/mines in the coastal zone. *Oceanography*, **14**(1), 55-56.

Voropayev, S.I., Testik, F., Boyer, D.L. and Fernando, H.J.S. 2001. Migrating ripples and burial of cobbles/mines in a coastal zone. *Proceedings of the 2001 International Symposium on Environmental Hydraulics, December 2001, Tempe, USA*, Accepted for publication.